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Gravel Road Maintenance Cost Allocation

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Abstract: In northern Ontario, the maintenance cost of industrial roads is shared by both industry and the Ministry of Transportation, on the basis of gross weight-distance (tonne-km) travelled. The existing system tends to allocate, disproportionately, the maintenance cost for damage caused by vehicles from both industry and the public. This inequity is due in part to the limitation in the existing system to account for the damage contribution from the bouncing and chattering of light vehicles. In an attempt to correct the shortcoming, this paper proposes an alternative approach which considers all types of surface damage that increase maintenance costs. The criteria used to estimate the damage include roughness and tonne-km. For the maintenance of industrial roads, these criteria represent a measure of surface distresses manifested in the form of corrugations, rutting and structural damage due to excessive loading. Finally, the proposed method assigns the cost reponsibility according to the average damage contribution by each road user, estimated on the basis of roughness and gross weight-distance travelled. This study concludes that the maintenance cost allocation to the public, in general, be increased from an average value of 31 to 42%.

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Key Words: corrugations, cost allocation method, gravel road maintenance, gross weight-distance (tonne-km), industrial roads, maintenance cost, roughness

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1/ Introduction

The Ministry of Transportation of Ontario (MTO) has made a commitment to subsidize the maintenance of industrial roads, proportional to the amount of public use. An industrial road is defined as a private road constructed and maintained by private industries for their use, as well as for the use of the general public. Industry generated traffic includes heavy transport trucks moving raw and processed materials for lumber, pulp or mining industries, service vehicles, employees commuting, and community deliveries and services. Public traffic generators include local area residents, tourists, and other commercial businesses using the road for access.

Currently, maintenance costs are shared by industry and MTO on the basis of gross vehicle weight-distance travelled per year (tonne-km). Recently, industries expressed concern regarding the maintenance cost allocation for unpaved industrial roads. This is due to a significant increase in the number of public light vehicles which has apparently increased the frequency of road surface grading. Based on industry's experience, the damage caused by the bouncing of light vehicles, particularly small trailers towed by passenger vehicles, is not adequately taken into account by the existing system. For instance, the present system suggests that the damage caused by a loaded 60 tonne log truck is equivalent to the damage caused by 30 light vehicles of 2 tonnes each. Is this a disproportionate value system or is the apparent deficiency in the system offset by the bouncing effect of empty log trucks doing the same amount of damage as the larger number of light vehicles?

Although this study on cost sharing determines equitable charges for each of the road users, a non-controversial solution for this problem may not exist; however, an assessment of cost allocation based on a rational system, deemed equitable by all users, needs to be identified.

Recognizing the above concerns, the Research and Development Branch has investigated the effect of an increased number of light vehicles on gravel road surface deterioration.

2/ Purpose

The purpose of this study is as follows:

1) To review the current literature concerning the assessment of vehicular damage on unpaved roads and to identify the potential use of available predictive models for estimating the damage on industrial roads caused by different road user vehicles.

2) To examine the existing cost allocation methods and to develop a theoretical framework using the models identified in Step 1 to determine the maintenance cost.
3) To recommend changes to the existing system and, if necessary, to compensate for damage caused by the bouncing effect of light vehicles and empty trucks.

3/ Literature Review

3.1/ Vehicular Damage on Gravel Roads

The extent of vehicular damage on gravel roads depends on the vehicle load, the frequency of travel, and the environment. Vehicular damage to unpaved roads increases under rainy or wet conditions, more than under dry conditions. In general, the types of traffic-related damage to unpaved roads can be identified as follows:

1) rutting
2) corrugations
3) potholes
4) gravel loss.

Rutting is defined as a surface depression in the wheel path, resulting from repeated vehicle passes, especially when the road is soft. This distress is usually associated with heavy vehicles, although repeated passes by certain types of light vehicles can accelerate the displacement of materials along the wheel path [1].

Corrugations (washboarding), are defined as closely spaced ridges and valleys (ripples) at fairly regular intervals. The ridges are perpendicular to the direction of traffic and usually form on hills, curves, in areas of acceleration or deceleration, and also in areas where the road is soft. They initiate from minor deformations due to heavier loads, but they are aggravated by the bouncing and chattering of light vehicles or empty trucks on the road [1]. Corrugations are not only uncomfortable for the occupants of vehicles, but they can cause considerable damage to vehicle suspension systems. Many papers describe the formation of corrugations and most [2, 3] support the theory that corrugations are formed and perpetuated by forced oscillations at the resonant frequency of vehicles' suspension and tire systems.

Potholes are bowl-shaped depressions in the road surface. Factors contributing to the formation of potholes are the combined effects of traffic and excessive moisture, the width of the road surface, the

type of surface material, and the condition of shoulders. Of these factors, the volume of traffic is the most important [4].

Gravel loss refers to the erosion of materials due to weathering, traffic and blading. For this study, no attempt was made to estimate gravel loss because grading remains the principal operation in maintaining the industrial roads in northern Ontario. Regular blading also prevents the permanent loss of granular materials because the material can be bladed back into wheel tracks before being lost in the ditch line [1].

3.2/ Assessment of Damage

The assessment of responsibility for gravel road damage, by individual road users, is a complex task, because of the difficulty in determining the extent of damage by different vehicles. Several theoretical analyses, coupled with experimental studies on gravel roads, have been carried out by the United Nations Development Program, the World Bank, and other agencies, to determine the influence of traffic loads, the environment, and materials on surface distresses [1, 5, 6]. As well, a number of analytical models have been developed which help examine the surface deterioration caused by both heavy and light vehicles. Based on these studies, three suitable parameters were identified to characterize different types of traffic-related surface distresses. These parameters will provide a basis for a comparative evaluation of the cumulative damage caused by industrial and public vehicles. They are:

1) roughness
2) rut depth
3) gross weight-distance travelled (tonne-km).

3.2.1/ Roughness

Roughness is defined as "deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads and drainage" [7]. Roughness relates directly to the ride quality of the pavement and acts as a suitable criterion to quantify the damage component from corrugations and potholes.

Hudson *et al.* developed roughness prediction models in connection with the results of a major study on gravel roads conducted in Brazil [5, 6]. From the study, the following model was selected to assess the combined influence of light and heavy vehicles operated by individual road users on roughness.

$$\text{Log}(R1 / Ro) = D[0.4313 - 0.1705T2 + 0.001159NC + 0.000895NT - 0.0002227NT \times G + S(-0.1442 - 0.0198G + 0.00621M - 0.0142PI - 0.000617NC)]$$

where:

Ro = roughness immediately after blading;

R1 = estimated roughness "D" days after blading;

D = number (in hundreds) of days since last blading;

T2 = surface-type dummy variable: 1 if clay, 0 if laterite or quartzite;

NC = average daily car and pickup traffic in both directions (< 5 tonnes);

NT = average daily bus and truck traffic in both directions (> 5 tonnes);

G = absolute value of grade (present);

S = seasonal dummy variable: 0 if dry, 1 if wet;

M = % surface material passing the #200 sieve; and

PI = plasticity index of surface material (%).

3.2.2/ Rut Depth

Rutting is used to estimate surface damage along the wheel paths due to wheel loads. In general, the higher the wheel load, the more severe the rutting, although repeated passes of certain types of light vehicles can hasten deformation along the wheel paths. Initially, rut depth models developed for two seasonal conditions [1] were considered for the analysis. However, a close examination of these models revealed that the assessment of damage responsibility, using these models, may lead to an inequitable cost allocation to each road user. This is because the existing models cannot reliably estimate the influence of heavy truck loads (the major contributing factor) on the rutting of gravel roads. Thus, the rut depth criterion is eliminated in this study to assess damage responsibility for gravel roads. Further, since rutting relates directly to traffic loads, the subsequent use of the gross weight-distance criterion acts as a substitute for the rut depth criterion.

3.2.3/ Gross Weight-Distance Travelled

The method for assessing damage using the gross weight-distance travelled (tonne-km) criterion and a sample calculation are both given in the Appendix. Studies have shown that heavy loads reduce the expected life of any roadway system. Heavy trucks on industrial roads carry an average load of about 40-60 tonnes. Therefore, the tonne-km criterion is used in addition to roughness, in the proposed method, to reflect the damage on roadway structures due to excessive loads. The most suitable criterion for comparing the induced damage due to heavy loads is axle-weight, rather than gross-weight. However, because of the absence of field data on axle weights, gross weight-distance travelled/year is used to assess the damage responsibility.

4/ Proposed Cost Allocation Method

4.1/ Approach

As discussed previously, the existing cost allocation method based on gross weight-distance travelled appears to conceal a significant amount of variation in the assignment of damage responsibility for the vehicles used by both the public and industry. In an attempt to overcome the shortcomings of the existing system, this paper proposes an alternative method which allocates the maintenance cost responsibility proportionally to the average damage contribution by the individual road user. The damage is assessed on the basis of roughness, and tonne-km, as described in Section 3. Using this criteria, the damage estimated represents a measure of different types of surface distresses caused by all vehicle classes. The following section shows the calculation of cost allocation based on the proposed new method using a typical example.

4.2/ Cost Allocation Calculations

To assess the cost responsibility using the proposed new method, the Manitouwadge-Caramat Industrial Road operated by Buchanan Forest Products Ltd is considered. The annual average daily traffic (AADT) generated by the company is 96: 74% heavy vehicles and 26% light vehicles. The public generates an AADT of 177: 14% heavy vehicles and 86% light vehicles. Roughness caused by company and public vehicles is calculated separately using the model discussed in Section 3.2.1. Table 1 shows these values.

Based on roughness, attributed mainly to corrugations and potholes, the company is responsible for 44% of the damage and the public for 56%. This supports the common theory that the bouncing and chattering of light vehicles used by the public hastens the development of corrugations. The existing weight-distance criterion assigns 68% responsibility to the company and 32% to the public.

The proposed method recommends the cost allocation for the individual road user must be proportional to the average damage contributions estimated using both criteria. Accordingly, the new system estimates 56% for the company and 44% for the public: an increase by 12% for the public. Looking at the amount of traffic generated by the public, and the type of damage caused by the bouncing effect of light vehicles, this increase in responsibility by the public is considered reasonable.

Similar calculations were performed for two other industrial roads, as shown in Tables 2 and 3. The percentage cost allocation for Sultan-Makwa Road is 45:55, while the existing system suggests 38:62 for

the public and company, respectively. For Northwest Industrial Road, the new system suggests 38:62, while the existing system gives 24:76 for the public and company, respectively.

There are several industrial roads in northern Ontario maintained by companies, with unknown AADT values. In the absence of a proper traffic count, it is suggested that a cost allocation payment be made on the basis of the average data obtained for the industrial roads considered above. This means that proposed cost sharing, obtained by averaging the values estimated for the three industrial roads and considered in the analyses (Appendix, Table 4), will be approximately 60:40 between the public and industry for industrial roads with unknown traffic distribution.

5/ Summary and Conclusion

The existing cost allocation method based on the tonne-km criterion tends to allocate maintenance cost disproportionately for the damage caused by vehicles from both industry and public. This problem is solved by incorporating into the existing system the damage factor caused by the bouncing and chattering of light vehicles used by the company and the public. Therefore, in the new system, the damage contribution from the individual road users is estimated in terms of road roughness and tonne-km. Subsequently, the cost allocation is recalculated by averaging the percent damage contribution assessed using roughness and tonne-km criteria. The study recommends an increase in cost allocation to the public from an average value of 31 to 42%.

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Table 1/ Maintenance cost allocation for Manitouwadge-Caramat Industrial Road

Road Users		Company		Public	
Trucks (NT)		71		24	
Cars (NC)		25		153	
Criteria		Roughness	tonne-km	Roughness	tonne-km
Seasonal Variation	Dry Condition	2.097Ro	—	2.843Ro	—
	Wet Condition	1.486Ro	—	1.68Ro	—
	Average	1.79Ro	13,271,493	2.23Ro	28,532,926
	Percent Ratio	44	68	56	32
	Overall Average	56		44	

Road Characteristics

Initial roughness:	Ro	Plastic Index:	2% (PI)
% passing #200:	8%	Material Type:	Clay (T2 = 1)
Grade:	2%	Duration:	100 days (D = 1)

Table 2/ Maintenance cost allocation for Sultan-Makwa Road

Road Users		Company		Public	
Trucks (NT)		17		6	
Cars (NC)		36		55	
Criteria		Roughness	tonne-km	Roughness	tonne-km
Seasonal Variation	Dry Condition	2.043Ro	—	2.124Ro	—
	Wet Condition	1.435Ro	—	1.443Ro	—
	Average	1.733Ro	4,500,000	1.783Ro	7,500,000
	Percent Ratio	49	62	51	38
	Overall Average	55		45	

Road Characteristics

Initial roughness:	Ro	Plastic Index:	2% (PI)
% passing #200:	8%	Material Type:	Clay (T2 = 1)
Grade:	2%	Duration:	100 days (D = 1)

Table 3/ Maintenance cost allocation for Northwestern-Industrial Road

Road Users		Company		Public	
Trucks (NT)		22		10	
Cars (NC)		32		75	
Criteria		Roughness	tonne-km	Roughness	tonne-km
Seasonal Variation	Dry Condition	2.031Ro	—	2.250Ro	—
	Wet Condition	1.425Ro	—	1.485Ro	—
	Average	1.728Ro	5,141,585	1.867Ro	16,026,830
	Percent Ratio	48	76	52	24
	Overall Average	62		38	

Road Characteristics

Initial roughness:	Ro	Plastic Index:	2% (PI)
% passing #200:	8%	Material Type:	Clay (T2 = 1)
Grade:	2%	Duration:	100 days (D = 1)

Table 4/ Percent cost allocation summary

ROAD	COMPANY		PUBLIC		ADDITIONAL INCREASE %
	Existing %	Proposed %	Existing %	Proposed %	
Manitouwadge-Caramat	68	56	32	44	12
Sultan-Makwa	62	55	38	45	7
N. W.	76	62	24	38	14
Average	68.66	57.66	31.33	42.3	11

Appendix

Manitouwadge-Caramat Industrial Road

Road Usage Analysis

I. General Information and Assumptions

- road length
  - Hwy. 614 to Hillsport access – 54 km
  - Hwy. 625 to Hillsport access – 39
  - total length – 93

- annual road usage
  - Buchanan – 230 days
  - public (commercial) – 260
  - public (general) – 365

- traffic statistics and source
  - Buchanan Forest Products Inc.
  - Twp. of Manitouwadge
  - M.N.R. (Terrace Bay)
  - Hillsport (1983 public meeting - updated)
  - periodic on-site inspections
  - 1984 - 1987 Traffic Surveys
    - average (total) AADT – 162
    - company – 51
    - Hillsport (public) – 11
    - through traffic (public) – 100

- vehicle weights (average of gross and tare)
  - light (car, stat. wag., van, 1/2 - 3/4 ton) – 2 t
  - supply truck – 5
  - fuel truck/bus – 15
  - tandem truck – 19
  - transport – 28
  - float – 40

- volume to weight conversion
  - 1 cord = 2.407 m^3 (solid wood)
  - softwood = 800 kg/m^3
  - hardwood = 990 kg/m^3

II. Calculations

A. Company Generated Traffic

Wood haul:		t-km/yr	t-km/yr
Swill-Rudder Area:			
1707 vehicles	x 58.5 t x 8.0 km	= 798,876	
543	x 67.5 x 8.0	= 293,220	
2250	x 20.0 x 8.0	= 360,000	
Michal-Sparky/Husak Area:			
1419 vehicles	x 58.5 t x 30.7 km	= 2,548,453	
1543	x 67.5 x 30.7	= 3,197,481	
2962	x 20.0 x 30.7	= 1,818,668	
Kawepiti-High Falls Area:			
640 vehicles	x 58.5 t x 42.2 km	= 1,579,968	
180	x 67.5 x 42.2	= 512,730	
820	x 20.0 x 42.2	= 692,080	
Reeves Lake Area:			
429 vehicles	x 67.5 t x 44.0 km	= 1,274,130	
429	x 20.0 x 44.0	= 377,520	
1515	x 58.5 x 48.9	= 4,333,884	
1515	x 20.0 x 48.9	= 1,481,670	
Hades-Styx-Bauler Area:			
2260 vehicles	x 58.5 t x 19.4 km	= 2,564,874	
2220	x 67.5 x 19.4	= 2,907,090	
4480	x 20.0 x 19.4	= 1,738,240	
			26,478,884

Associated traffic		
Operating Unit #1		
2 vehicles	x 15 t x 19.4 km x 95 days	= 55,290
8	x 2 x 19.4 x 95	= 29,488
Operating Unit #2		
20 vehicles	x 2 t x 30.6 km x 50 days	= 61,200
Operating Unit #3		
16 vehicles	x 2 t x 30.6 km x 230 days	= 225,216

	t-km/yr	t-km/yr
Operating Unit #4		
20 vehicles x 2 t x 42.2 km x 55 days	= 92,840	
Operating Unit #5		
2 vehicles x 3 t x 6.4 km x 230 days	= 8,832	
8 x 2 x 6.4 x 230	= 23,552	
Superintendent/Forestry		
8 vehicles x 2 t x 93 km x 50 wks.	= 74,400	
Float		
5 vehicles x 40 t x 93 km x 46 wks.	= 855,600	
Fuel		
4 vehicles x 15 t x 93 km x 46 wks	= 256,680	
Gravel		
10 vehicles x 18 t x 64.4 km x 32 wks.	= 370,944	
		2,054,042
Total Company generated traffic		**28,532,926**

B. Public Generated Traffic

Twp. of Manitouwadge

Lagoon					t-km/yr	t-km/yr
2 light vehicles	x 2 t	x 0.3 km	x 365 days	=	438	
2	x 2	x 0.3	x 52 wks	=	62	
2 fuel trucks	x 15	x 0.3	x 12 mth	=	108	
2 grader/loader	x 12	x 0.3	x 48 days	=	346	
Sand Lake borrow pit						
96 trucks	x 19 t	x 3.6 km	x 30 days	=	196,992	
32	x 10	x 3.6	x 30	=	34,560	
2 loaders	x 12	x 3.6	x 30	=	2,592	
144 trailer dumps	x 33	x 3.6	x 7	=	119,750	
Landfill site						
2 light vehicles	x 2 t	x 6.4 km	x 365 days	=	9,344	
2	x 2	x 6.4	x 260	=	6,656	
40	x 2.5	x 6.4	x 365	=	233,600	
16 trucks	x 19	x 6.4	x 52 wks	=	101,171	
2 loaders	x 10	x 6.4	x 52	=	6,656	
2 graders	x 14	x 6.4	x 12	=	2,150	
Recreation areas						
8 light vehicles	x 2 t	x 4.1 km	x 26 wks	=	1,706	
16	x 2 t	x 5.7	x 126 days	=	22,982	
						739,113

Hillsport (Lunam Road)

- Lunam Road to Caramat is 39 km.
- Lunam Road to Manitouwadge is 54 km.

6 light vehicles	x 2 t	x 39 km	x 52 wks.	=	24,336
6	x 2	x 39	x 41	=	19,188
10	x 2	x 39	x 12 mth.	=	9,360
2 fuel trucks	x 15	x 39	x 6	=	7,020
2 septic trucks	x 15	x 39	x 1 yr.	=	1,170
10 light vehicles	x 2	x 54	x 365 days	=	394,200
4	x 2	x 54	x 52 wks	=	22,464
4	x 2	x 54	x 12 mth	=	5,184
6 fuel trucks	x 15	x 54	x 12	=	58,320
6 ambulances	x 2	x 54	x 1 yr	=	648
					541,890

					t-km/yr	t-km/yr
Through Traffic						
89 light vehicles	x 2 t	x 93 km	x 365 days	=	6,042,210	
5 trucks	x 15	x 93	x 260	=	1,813,500	
1	x 19	x 93	x 260	=	459,420	
4 transports	x 28	x 93	x 260	=	2,708,160	
1 float	x 40	x 93	x 260	=	967,200	
						11,990,490
Total public generated traffic						**13,271,493**

III. Summary

Public generated traffic = 13,271,493 t-km/yr or 32%.

Company generated traffic = 28,532,926 t-km/yr or 68%.

Total traffic = 41,804,419